Advancements and the Future Outlook of Charting the Nigerian Navigation Channel

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ABSTRACT

The need for achieving safe waterways for navigation, engineering, exploration, security and other marine operations cannot be overemphasized and should be attained using precise methods and equipment. The Hydrographic process still remains the only systematic means through which spatial information about our marine environment (oceans, seas, rivers etc.) are acquired for charting purposes so as to aid analysis and decision making. In Nigeria today, most marine operations and mostly the Nigerian Navy is dependent on the Hydrographic process for smooth operations required for security, trading, engineering etc. therefore maintaining the integrity of the hydrographic process is of uttermost importance. To maintain the integrity of the hydrographic process used for charting our navigational channels, the progressive evolution of this process shall be assessed: from the earliest methods that directly sounded navigational channels using weighted lead lines and graduated poles to provide water depths to Wire Drag methods used to identify physical features on the marine environment, then to the 1930s when acoustic waves were applied in the Echo Sounder to indirectly ascertain seabed profile, and the use of instruments like Multi Beam Echo Sounders, Magnetometer, Side Scan Sonar, etc. for detailed Bathymetric and Geophysical Survey Projects, and presently to the use of Remotely Operated Vehicles (ROV) and satellites in space to monitor sea level rise. All these methods are all driven by the insatiable need for more advancements and sophistication in providing information about our marine environment. This paper renders a detailed discourse on the progressive advancements of the hydrographic process used in charting of our marine environment. It also provides recommendations on the future outlook of this process so as to preserve the accuracy in charting our Nigerian navigational channel.

***Keywords**: Hydrographic Survey, Navigation, Trends, Recommendation, Bathymetry, Geophysical.*

INTRODUCTION

Hydrography as defined by the National Ocean service "is the science that **measures and describes the physical features** of the navigable portion of the Earth's surface and adjoining coastal areas. Hydrographic Surveyors study these bodies of water to see what the "floor" looks like", were Hydrographic Survey method is the principal means in which this spatial data is collected and the basis for delineating a navigational channel for various economic benefits in: transportation, trading, security, exploration, engineering etc. Furthermore, Hydrography focuses on the deduction of underwater topography from numerous discrete observations of depth. They are also carried out for the following:

1. Provide basic data for nautical charting
2. Obtaining site detail for alongshore or offshore construction
3. Assessing the condition of port and marina facilities
4. Measuring the quantities in dredging projects and
5. Determination of the extent of siltation and for numerous other reasons.

But this paper's focus is on Nautical Chart making.

All marine bodies (Oceans, Seas, Rivers etc.) covering all countries in the world are consequent on hydrographic survey methods for mapping out navigational channels, and Nigerian waters are also being charted too using best survey methods, as the Nigerian Navy Hydrographic Office (NNHO) commenced chart production with the unveiling of Nigeria's first National Chart at the 2019 World Hydrography Day celebration in Lagos (Nigerian Navy Hydrographic Office, n.d.) in a bid to chart all navigable Nigerian waters.

Over the years, these survey methods have advanced steadily from direct methods to the dominant indirect methods of our present day. Where these methods have evolved, the need to preserve and enhance accuracy in the survey methods used in charting these navigation channels has remained insatiable.

This paper aims at pointing out the advancements made in hydrographic surveying from where we were **yesterday**, where we are **today** and the **future** outlook of hydrographic survey methods used in charting the Nigerian navigational channels. This aim is objectively achieved through:

I. Reviewing the progressive trend of Hydrographic Survey methods
II. Providing recommendations the future outlook, in order to maintain accuracy in the practice of Hydrography in Nigeria

NAUTICAL CHART

A map/chart is the final product of any survey carried out for any area of interest. It is the visual representation of any specific marine environment in consideration and also the basis for every waterborne operation. Just like a basic survey map/plan, the Nautical Chart presents a graphical spatial relationship of features within any marine environment (oceans, seas, rivers etc.). Information on the Nautical Chart usually includes: areas of varying water depths/tidal information, position of wreck/obstacles (navigational hazards), natural/manmade features, map projection parameters and navigational channels/routes. This information on the nautical chart is represented using signifying colors and symbols according to IHO standards S-4 Regulations and Specifications for IHO International Charts (IHO, 2018).

The Act of Parliament 1964 and the Armed Forces Cap Act A20 LFN of Nigeria empowered the Nigerian Navy to chart all Nigerian waters, while the Nigerian Navy Hydrographic Office (NNHO) a subsidiary of the Nigerian Navy has been invested with the power to produce/issue Nautical Charts (updates, corrections) about Nigerian waters (Nigerian Navy Hydrographic Office n.d.). The NNHO makes this available on demand either via an electronic web link or through a paper sheet, so that end users can have a proper navigational guide in their marine operations. It is important to note that the confidence of a nautical chart is dependent on the accuracy of the survey method employed.

TRENDS OF HYDROGRAPHIC SURVEY FOR NAUTICAL CHART MAKING

The constant need for accuracy has remained the driving force in the advancements of the survey methods used in charting navigation channels. As these methods progressed, sophistication of equipment and methodology progressed directly too. These methods are commonly divided into two:

1. Direct Methods

2. Indirect Methods

These methods have been the classification of all past and present survey methods used in charting our marine environment (navigation channels). Conclusively, all hydrographic survey methods have gradually advanced from direct methods which produced incomplete and interpolated information to indirect methods which gave more reliable and comprehensive information on any marine environment of interest.

1. Direct Methods

The earliest use of direct methods for hydrographic survey cannot be traced, as there are no official records to its first use and invention. But it is important to note that because there was little or no information (Nautical Charts) for sailing ships on coastal waters, the United States congress in 1790 began authorizing specific and limited surveys of the coast (NOAA, 2017).

The survey methodology involved in Direct Methods includes using of graduated lines, poles, wire and sextant (3-D position fix) to take measurements that determines depth difference and features (wrecks) on the seabed. The earliest charts produced using these methods were comparatively reliable (Ojinnaka, 2007) although not accurate in its totality. This because: the graduated line and pole method, inasmuch as they gave accurate depth readings to the seabed, the method was laborious, time consuming and its area of coverage limited thereby a lot of information on the earliest nautical charts were interpolated. But the invention of the early 1900’s Wire Drag method revolutionized the practice of Hydrographic Survey in that it had a lot of coverage (unlike the graduated pole and lead line method) and the position of wrecks and other navigational hazards could be identified. NOAA associates Nicholas Heck of the Coast Geodetic Survey, a predecessor of the US Coast Survey to its breakthrough (National Ocean Service et al, 2007). The Wire Drag method had the attachment of each edge of a wire net (at a specified depth) to two different vessels (Boat or Ship as seen in ***Fig 1***) and while the vessels moved and encountered an obstruction, it would make a V shape exposing the location and depth of the obstruction (NOAA as cited in Donald and Parnell, 2018). This Wire Drag method as seen in ***Fig 1*** was a major upgrade to the graduated pole and lead line method because a lot of obstacles (wrecks and other navigational hazards) which were missed by the graduated and lead line method could now be identified.

Fig 1 showing two Vessels carrying out Wire Drag Survey. *Source: NOAA as cited in Donald and Parnell, 2018*

The United States Coast Survey (USCS) depended so much on the Wire Drag method from the early 1900 to the early 1990 (National Ocean Service et al, 2007) with this method likely accounting a certain percentage in the over 11,600 Hydrographic Surveys carried out by the USCS till date (National Ocean Service et al, 2007). Inasmuch as this method revolutionized the practice of hydrographic survey, its area of coverage was limited.

2. Indirect Method

Inasmuch as the Wire Drag method was more reliable than the graduated pole method, in that it provided more details about the seabed, the need for sophistication in equipment and methodology without compromising on accuracy was also needed. This ushered in the dominant use of **sonar enabled equipment(s)** and **remote sensing** techniques to indirectly determine depths and position of physical features which hamper navigational.

Sonar Systems

In recent times, the available means of carrying out Hydrographic Survey operation uses Sonar sensors which propagate acoustic waves to carry out underwater measurements. These sensors deployed into the marine environment have the ability to provide seabed profile/depths, positions and images of wrecks and obstacles, in the water body etc. plus they can thrive in both fresh and salt water environment. Single/Multi Beam Echo Sounders, Side Scan Sonars etc. are common instruments employed in this indirect method. The two basic surveys applied in charting navigation channels include; Bathymetric Survey and Physical feature Identification Surveys.

i. **Bathymetric Survey**: Position Fixing and Sounding are the basic features of Bathymetry so as to determine depth variants and the topography of the seafloor from which navigable water channels can be delineated accurately based on bathymetric survey carried out on the marine environment. Echo Sounders are the basic equipment used for sounding to determine depth variants. The Titanic disaster of 1913 was the driving force that led German Physicist Alexander Behm, who in his bid to determine how to detect iceberg, discovered the use of sound pulses to determine depths from the surface to the bottom of the sea (Sana, 2013). But the development and implementation of the Echo Sounder as an equipment can be traced to the 1930's when single beam sound waves were sent out from a transducer directly below a vessel (NOAA, 2017). Nowadays, the Echo Sounder has become a mainstay in Bathymetry, although Multi Beam Echo Sounders (MBES) are much more preferably used as they send out a spread of sound waves in one single ping as seen in ***Fig2*** with a 100%

coverage, unlike the single beam which sends out only one line of sound wave at one ping and leaving various unsounded gaps.

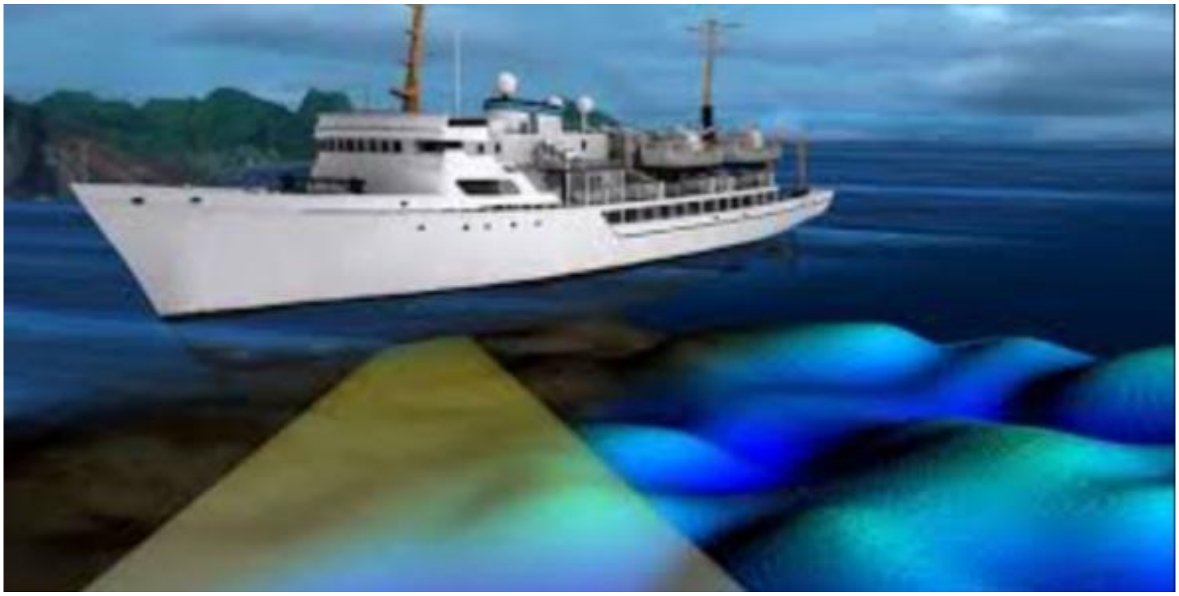

Fig2 Showing a simulated Multi Beam Echo Sounder sound wave. *Source Ocean News and Technology Magazine (2019)*

Information about Nigerian water(s) are also being determined using bathymetric surveys, with the existence of various literatures/projects giving credence to that fact. The uniqueness of these existing literatures and projects is the similarity in Equipment, Data Acquisition and Data Processing: (Tata et al, 2019) carried out a Bathymetric Survey on a part of Lagos Lagoon: Data was acquired using an Echo Sounder, Absolute Positioning (Handheld GPS), Moving Vessel (Boat), Transducer, PowerNav for navigation etc. while Hypack, ArcGIS. AutoCAD, Surfer etc. were used for data processing and charting. Also (Badejo and Adewuyi, 2019) carried out a Bathymetric Survey on some parts of Badagry Creek and Yewa River in Lagos State Nigeria: Data was acquired using an Echo Sounder, RTK-GPS (Differential Positioning), while Hypack, ArcGIS were used for mapping/charting,

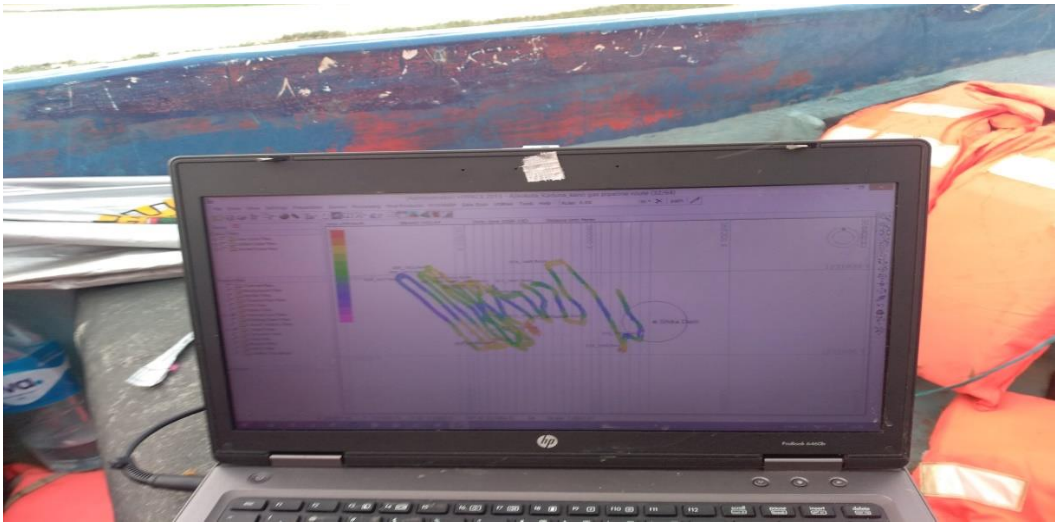

Fig 3: Bathymetric Survey result on Hypack interface. *Source: AKK Project 2020*

The AKK (Ajaokuta Kaduna Kano) is a gas pipeline project managed by NNPC. The proposed gas pipeline route traverses from Ajaokuta in Kogi State, through Niger/Kaduna State and terminates at Kano State. With some water bodies like Chiromawa, Hadejija, Shika, Garnin Jatau, Sarkin Pawa etc. among others found within the over 500km proposed gas pipeline route. The scope of work specified a bathymetric survey using a single beam Echo Sounder, Survey vessel, DGPS system interfaced to a notebook navigation and data logging system, so as to determine the relationship between water levels and ground levels, for the production of a profile map of the Gas Pipeline route. (Nigerian National Petroleum Corporation, 2019). **Fig 3** shows the result of the Bathymetric Survey of Shika River as seen in the Hypack environment which was the navigation and data logging system used during the execution of AKK survey works in 2020, as specified for the project.

It is also significant to note that as Bathymetric survey is important in projects carried out in high elevation Northern Nigeria, so it is of highest important to various individuals and companies who carry out various bathymetric activities in our coastal areas for purposes ranging from research to financial profits: Just as (Tata et al, 2019) cited above carried out a Bathymetric Survey on the Lagos lagoon, (Chukwu and Badejo, 2015) carried out the same bathymetric survey on the same

Lagos lagoon with a different purpose to study seabed topography change over a six year period from 2008-2013: results from the research showed sediment changes in the six year period, while the research recommended more studies on the Lagos lagoon as it affects marine transport.

ii Physical Feature Identification Survey: In accessing the progressive evolution of the hydrographic methods used in mapping seafloors, the 1950's to 1970's saw the offering of Side Scan Sonars and Multi Beam Swathe systems in providing a qualitative means of mapping our seafloors and identifying positions of wrecks and features (NOAA, 2017). This on its own solved the problem of incomplete depth determination as encountered in the Single Beam Echo Sounder (SBES) and the limitations in identifying physical features as encountered in the Wire Drag method. These days, in the execution of various marine projects applied in engineering, navigation, research, offshore survey inspections etc., full spread Bathymetric and Geophysical surveys are recommended, as such combination provide a better understanding on the interest marine environment.

Geophysical Survey is **not** basically hydrographic survey, and it is **totally different** in its entirety, but its principles and equipment(s) have applications in most underwater projects including mapping of navigable waters.

The scope of works and equipment(s) involved in Geophysical Survey for charting navigational channels include but are not limited to the following:

a. Bathymetric Survey: To determine variation in water depths, so as to understand the seabed topography. This is achieved by using an Echo Sounder, preferably a Multi Beam Echo Sounder.
b. Determination of geo-hazards: especially ferrous materials underneath the seafloor, this is done using a magnetometer which has the ability to identify any magnetic field (metallic objects) around the marine environment of interest.

c. Identification of debris and wreckages on the seabed: This is achieved using a Side Scan Sonar (SSS) which provides a recorded video/pictorial imagery of inherent positions of debris and wreckages found on the marine environment of interest.
d. Navigation and Positioning using mainly GNSS Satellite Based Augmentation System (SBAS).
e. Survey Vessel as a moving platform which carries all the sensors (equipment)
f. Data processing using software(s) like Hypack, AutoCAD, Surfer etc.

Inasmuch as Geophysical Survey equipment(s) are expensive, it still remains the most **accessible** means of Hydrographic Survey available for charting all navigable waters in Nigeria, as it gives more detailed information on the seabed, as seen in (Egbuh, 2006) who carried out a hydrographic survey in the Lagos Port area for purposes of safe navigation: the equipment deployed for data acquisition included Echo Sounder, Magnetometer, Side Scan Sonar etc. Data was processed using AutoCAD, Hypack, HydroCAD, SurvCAD, GPS Path Finder office, with results showing depth variants from 1.1m to 24m and a total of One hundred and nine (109) wreckages in the entire survey area. The high numbers of wreckages simply shows the significance of detailed bathymetric and geophysical survey in delineating navigational channels. As the results from this survey shows a great number of hazards inherent to safe navigation. Now with this methodology and equipment(s), recommendations could be made for routine dredging of navigational channels, so as to maintain ease in vessel navigation.

Fig 3 and Fig 4 below shows some equipment(s) employed in identifying Physical features which could impede safe navigation.

Fig 3: SSS image on display on Topside, and showing a wrecked boat. *Source: JW Fishers (undated)*

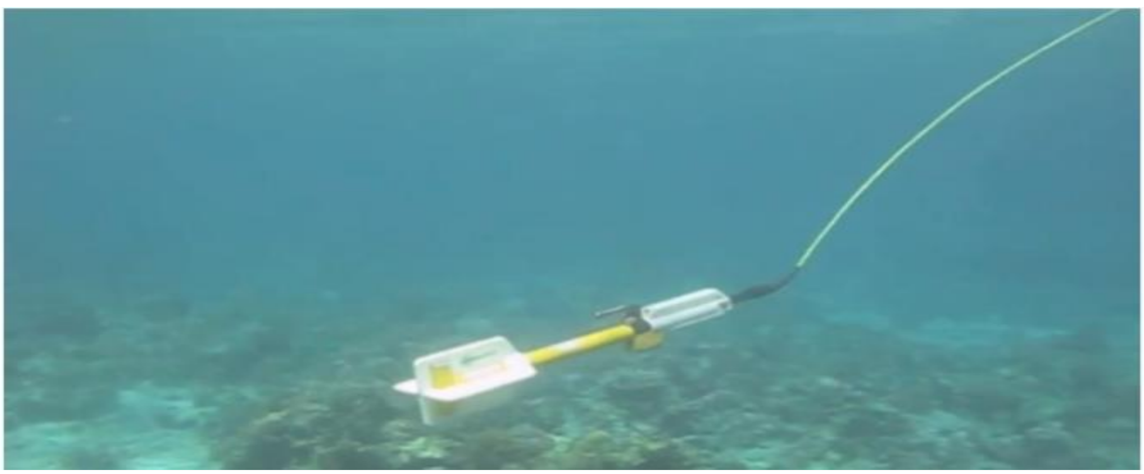

Fig 5: G-882 Geometrics Magnetometer deployed in Nampula Mozambique. *Source: Arqueonates Worldwide (undated)*

Remote Sensing Techniques

As the quest for improved precision in data acquisition for hydrographic survey has continued, there has been rapid development of modern technologies in remote sensing methods. Some of these new techniques which have been applied in bathymetric data collection have been described as "non-traditional" (Leder *et al*, 2020). They include; Unmanned Underwater Vehicles (UUV), Light Detection and Ranging (LiDAR) platforms and Satellite Derived Bathymetry (SDB)

i. Unmanned Underwater Vehicles: UUVs are products of robotic engineering applied in modern day hydrographic survey, either in Remotely Operated Underwater Vehicles (ROV) which requires tethered connecting cables and a human operator for functionality or an Autonomous Underwater Vehicles (AUV)whose operations are automated.

The commercial introduction of ROVs could be traced to the 1970's (Leder et al. 2018) which was a solution to Hydrographic survey in areas inaccessible to survey vessels to deploy sonar systems like the MBES, SSS etc. as described earlier. Currently, hydrographic uses for ROV include object identification (such as navigational hazards), vessel hull inspections and least depth determination (Leder et al 2018) with lighting and sonar cameras which carry out these tasks, thereby providing real time video and pictorial imageries of the interest marine environment.

ii. LiDAR Platforms: Several researches have stated that investigations have been carried out on the derivation of bathymetric data from satellite since the 1970s (Mavraeidopoulos *et al*, 2017; Jegat *et al*, 2016). However with the advancements in satellite technology, more work has been carried out on these techniques. An importance of bathymetric surveys in nautical navigation of shallow water is to avoid stranding (Sagawa *et al*. 2019). The traditional techniques such as the sonar systems as earlier described can at an instant measure a width equal to twice the depth of water. However, a shortcoming of this technique is that it cannot measure shallow waters effectively (Smith and Sandwell, 2004). The Lidar platforms have been adopted in hydrographic surveying of recent as can be seen in literatures such as (Sagawa et al, 2019; Irish and Lillycrop, 1999; Leder *et al*, 2020). (Humboldt State university, 2016) highlights that there are three types of Lidar platforms: (i) Ground based (ii) Aerial platform such as the Aerial laser scanning (ALS) and Drone Laser Scanning (DLS) and (iii) Satellite based platforms.

However, (Leatherman, 2003) classifies LiDAR based on two purposes, either Topographic or Bathymetric: were the Topographic LiDAR uses near-infrared beam to map land surfaces, the Bathymetric LiDAR uses infrared and green laser beam.

Bathymetric LiDAR is employed in hydrographic survey to capture geospatial data of the coastline and shallow waters (Leder *et al.,* 2020). A major plus to Bathymetric Lidar is that they are used in areas that are inaccessible to survey vessels (Zhang et al., 2019). A limitation in the use of ALB is that the target area must be in a flight capable area. Another limitation is the extremely high cost of ALB (Sagawa et al., 2019). This means that there will be insufficient data for areas that the survey vessels cannot access or that the airplanes cannot operate.

Satellite Derived Bathymetry

Satellite Derived Bathymetry (SDB) is defined as the determination of depth information by analyzing satellite images (Sagawa *et al*, 2019). This is one of the currently used state-of-the –art technologies in the estimation of depth using remote sensing techniques by employing multi-spectral or hyper-spectral sensors (Sagawa *et al*, 2019). Currently, SDB data has potential to become one of the main low cost sources of spatial data especially in hydrographic surveying (Leder *et al,* 2020). Further reads on SDB can be found in (Sagawa *et al,* 2019; Lyzenga *et al,* 2006; Kao *et al*, 2009; Manessa *et al.,* 2016; Mavraeidopoulos *et al*., 2017; Leder *et al.,* 2020; Gao, 2009; Pe'eri *et al.,* 2013).

Artificial Intelligence (AI)

Artificial Intelligence is an upcoming advancement in Hydrographic, as there are no dominant records of its use in Hydrographic survey. Artificial Intelligence involves embedding human capacities of logic, understanding, perception, reasoning, creativity etc. into a machine so that it can apply such capacities to any phenomenon of interest. AI has been employed in almost every sector of technology, and Hydrography is not a back bencher to this present advancement, as the Esri

GeoAI has employed machine learning and deep learning tools in ArcGIS to create point feature class containing shipwreck point and also provide charts of marine environment (Snow et al.2020).

RECOMMENDATIONS ON THE FUTURE OUTLOOK

To achieve this paper's aim of preserving the precision for mapping the Nigerian navigational channels, the progressive trend in hydrographic survey had to be reviewed from direct to indirect methods, ushering in more sophisticated equipment(s) for a precise and detailed depth determination and mapping of physical features. The following are some recommendations that if implemented could redefine the practice of hydrography in Nigeria with accuracy being the driving force.

1. **Involvement of Key Players**: Inasmuch as the Nigerian Navy is empowered to chart all Nigerian waters and delineate navigable waters, the seamlessness of achieving this is not feasible if all hydrography professionals are not involved. This includes call for all research works on all Nigerian waters and projects carried out by individuals and companies in the past, assessing their results with proper quality checks and compiling them, using it as base information for navigation and mapping of uncharted Nigerian waters.

2. **Satellite Systems**: Satellite systems seem to be the present and future of science and technology. More exploration and utilization of the technologies in satellite systems could be focused in remotely charting Nigerian Waters for the delineation of navigational channels. This might be expensive, considering the cost of building and launching a satellite, but the Nigerian Navy could latch on to the already existing satellites in space which could also be used to provide Satellite Based Augmentation System (SBAS) corrections and provide real time information on Nigerian navigation channels to vessels who have been granted permission to the frequency. This on its own is economically beneficial and guarantees security of our water ways for various offshore projects in trading, security, transportation, Oil and Gas etc.

3. **Exploring Advancements in AI and Programming**: There is a saying that mapping the moon's surface is easier than mapping the water bodies. This implores the Nigerian Navy to explore advancements in Artificial Intelligence and Programming as a means to map Nigerian waters for efficient delineation navigable channels.

4. **Quality Control:** The need for a Quality Control team which regulates hydro survey is important. A team that ensures that all standards for the practice of Hydrographic survey are followed, and also keeps a compilation of charts on Nigerian waters so as to maintain uniformity in practice.

5. **Training:** Because Hydrographic Survey is not as common as the regular onshore surveys, there are very few skilled in this practice. This stresses the need for adequate training or an improvement of the existing curriculum in Nigerian military academies, universities, polytechnics and colleges of education, so as to equip individuals with hands-on practical knowledge in the practice of accurate Hydrographic survey. For the preservation of accuracy in the practice of hydrographic Survey in Nigeria is determinate on the proper framework laid for the future generation.

CONCLUSION

The understanding of the progressive trend was crucial to recommending of the future outlook of charting the Nigerian navigational channels. This progressive trend has graduated steadily from the direct methods to the dominant indirect methods. But it is noteworthy to say that all succeeding methods were solutions to the limitations of the previous methods which were driven by the need for better accuracy and sophistication. Inasmuch as this paper has tried to proffer some recommendation, the future still seems unpredictable as it is probable that better methods and equipment(s) are expected to redefine the limitations of the present day dominant methods.

REFERENCES

Badejo O.T and Adewuyi G.k (2019). Bathymetric Survey and Topographic Survey changes investigation of part of Badagry Creek and Yewa River, Lagos State, Southwest Nigeria. *Journal of Geography, Environment and Earth Science International.*

Chukwu F.N and Badejo O.T (2015). Bathymetric Survey Investigation for Lagos Lagoon Seabed Topographical Changes. *Journal of Geosciences and Geomatics, 2015, Vol. 3, No. 2, 37-43*

Donald W and Parnell P.E (2016). Guide to Hydrographic Survey*. Original Courseware.*

Department of Commerce National Oceanic and Atmospheric Administration National Oceanic Service and Department of Defense, Defense Mapping Agency Hydrographic/Topographic Center. (1984). Chart No.1 United States of America Nautical Chart Symbols and Abbreviations. National Oceanic and Atmospheric Administration National Oceanic Service. *Washington D.C. 20230*

Egbuh I.N (2006). Charting Nigerian Waters for Safer Navigation. *FIG Regional Conference 2006 Accra Ghana 8-11 March 2006.*

Gao, J (2009). Bathymetric mapping by means of remote sensing: Methods, accuracy and limitations, Progress in Physical Geography, *33, 103-116.*

Humboldt State University (2016). GSP 2016 - Introduction to Remote Sensing. Lidar Overview. Humboldt State Geospatial. *Online,http://gsp.humboldt.edu/OLM/Courses/GSP_216_Online/lesson7-1/overview.html,29.01.2020.*

International Hydrographic Organization (2018). Regulations of the IHO for International (INT) Charts and Chart specifications of the IHO. *International Hydrographic Organization Monaco*

Irish, J.L.; Lillycrop, W.J. (1999) Scanning laser mapping of the coastal zone: The SHOALS system. *ISPRS J. Photogramm. Remote Sens.* 1999, 54, 123–129. [CrossRef]

Kao, H.-M.; Ren, H.; Lee, C.-S.; Chang, C.-P.; Yen, J.-Y.; Lin, T.-H. (2009). Determination of shallow water depth using optical satellite images. *Int. J. Remote Sens*., 30, 6241–6260. [CrossRef]

Leatherman, S. P. (2003**).** Shoreline Change Mapping and Management along the U.S. East Coast, *Journal of Coastal Research*, Vol. No. Special Issue 38, 5-13.

Leder, N. and Leder, T.D. (2018). Analysis of State- of-the- art Hydrographic Survey Technologies. *FIG working Week 2020*. Smart Surveyors for land and water management. Amsterdam, the Netherlands. 10 -14 May, 2020.

Leder, N., Leder, T.D. and Bacic, S. (2020). Unmanned Vehicle Systems in Hydrographic Survey-New Opportunities and Challenges. *International Conference on Transport Science Portoroz 2018*. Conference Paper 14-15, June 2018.

Lyzenga, D.R.; Malinas, N.P.; Tanis, F.J. (2006) Multispectral Bathymetry using a simple physically based algorithm. IEEE Trans. *Geosci. Remote Sens*, 44, 2251–2258. [CrossRef]

Manessa, M.D.M.; Kanno, A.; Sekine, M.; Haidar, M.; Yamamoto, K.; Imai, T.; Higuchi, T. (2016). Satellite-derived bathymetry using random forest algorithm and worldview-2 Imagery. Geoplan. *J. Geomat. Plan*., 3, 117–126. [CrossRef]

Mavraeidopoulos, A.K.; Pallikaris, A.; Oikonomou, E. (2017). Satellite Derived Bathymetry (SDB) and Safety of Navigation. *Int. Hydrogr. Rev*. 17, 7–20.

National Ocean Service, National Oceanic and Atmospheric Administration, U.S Department of Commerce, USA.gov (2007). Hydrographic Survey Techniques.*http://celebrating200years.noaa.gov/*

National Oceanic and Atmospheric Administration (2017). History of Hydrographic Surveying. *http://nautical charts.nooa.gov*

Nigerian National Petroleum Corporation (2019). Ajaokuta Kaduna Kano Gas Pipeline Project-Technical Requirements for survey works.

Nigerian Navy Hydrographic Office (Undated). https://www.nnho.ng

Ojinnaka O.C (2007). Principles of Hydrographic Surveying from Sextant to Satellite. *EL' Demak Publishers*

Pe'eri S, Azuike C and Parrish C (2013). Satellite-derived Bathymetry - A Reconnaissance Tool for Hydrography, *Hydro Int*. (17), 16-19.

Tata H, Nzelibe I.O and Faneye A.J (2019). Bathymetric Mapping for Safe Navigation: A case study of Part of Lagos Lagoon*. African Publications and Research International Vol.14 No.3 ISSN: 1896-6783*

Sagawa, T., Yamashita, Y., Okumura, T. and Yamanokuchi, T. (2019). Satellite Derived Bathymetry Using Machine Learning and Multi-Temporal Satellite Images. *Remote Sens*. 2019, 11, 1155; doi:10.3390/rs11101155.

Sana .S. (2013). Radio Propagation Measurements and Channel Modelling. *John Wiley & Sons. p.424. ISSN 9781118502327*

Smith, W and Sandwell, D. (2004). Conventional Bathymetry, Bathymetry from Space, and Geodetic Altimetry. *Oceanography*, 17, 8–23. [CrossRef]

Snow S., Yu D and Hosuru M. (2020). A Presentation on Esri Hydrographic Application of AI. *Online, https://www.youtube.com/watch?v=gJeMCBJwCrA*

Zhang, Z., Zhang, J., Ma, Y., Tian, H. and Jiang, T., (2019). Retrieval of Nearshore Bathymetry around Ganquan Island from LiDAR Waveform and QuickBird Image, *Applied Sciences,* 9(20), 4375.